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Toulon FRANCE.

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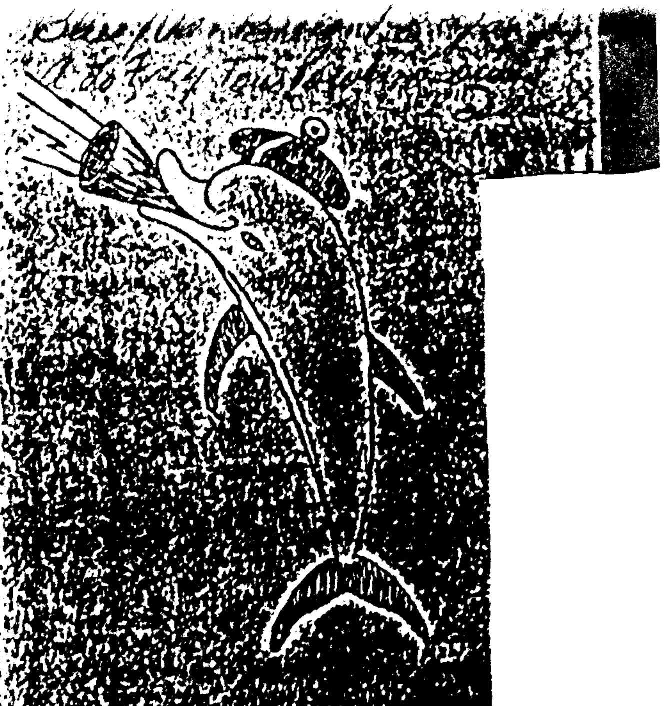

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TEXTE DES CONFERENCES

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M. Daux, B. Hamonic, O.B. Wilson, J.N. Decarpigny.

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Session 5

11h30 - 12h10

MAGNETO-HYDRODYNAMIC and THERMOACOUSTIC MECHANISMS FOR GENERATION OF SOUND IN SEAWATER

MECANISMES MAGNETO-HYDRODYNANIQUES ET THERMOACOUSTIQUES POUR LA GENERATION DE SONS SOUS MARINS

Steve L. GARRETT, Naval Postgraduate School, Monterey, CA, USA
Tom GABRIELSON, Naval Air Development Center, Warminster, PA, USA

12h10 - 12h40

A LOW FREQUENCY TOW-POWERED SOUND SOURCE

UNE SOURCE BASSE FREQUENCE ACTIONNEE PAR REMORQUAGE

Joe BLUE, A.L. VAN BUREN, Naval Research Laboratory, USRD, Orlando, FL, USA
LT Paul A. SEMPER, Navy Nuclear Power School, Orlando, FL, USA

13h00 - 15h00 *LUNCH* DEJEUNER

15h00 - 16h20

SESSION 6: *LOW FREQUENCY ELECTRONIC* SYSTEMS
LES DISPOSITIFS ELECTRONIQUES BASSE FREQUENCE

Chairman: **Jean-Noël DECARPIGNY**
ISEN-RECHERCHE, Lille, France

15h00 - 15h40

ELECTRONIC NEEDS FOR HIGH POWER TRANSDUCERS

LES BESOINS RELATIFS A L'ELECTRONIQUE POUR LES TRANSDUCTEUR DE FORTE PUISSANCE

George G. DIXON, Stephen R. LEYLAND,
Marconi Command and Control Systems, New Parks, Leicester, England

15h40 - 16h20

ELECTRONIC SYSTEMS MODELING

MODELISATION DES SYSTEMES ELECTRONIQUES

Jean-Marc CAPRON, ISEN-RECHERCHE, Lille, France
Serge FAURE, GERDSM, DCAN, Toulon, France

16h20 - 16h50 *BREAK* PAUSE

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This paper discusses resonant cavities and their potential sound pressure output when they are modulated hydrodynamically. Rough calculations show that in the frequency range of 10 to 100 Hz source levels in excess of 200 dB re 1 micropascal should be achievable. Experimental data from three suboptimum devices showed source levels of 182 dB at 16.6 and 50 Hz and 168 dB at 34.5 Hz. It is expected that with appropriate designs one can achieve greater than 200 dB from 10 to 100 Hz with fairly small, lightweight devices. Further, with innovative designs one should be able to obtain frequency diversity and perhaps broad bandwidth with a single device.

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A low-frequency, tow-powered sound source

J.E. Blue, A.L. Van Buren

Naval Research Laboratory, Underwater Sound Reference Detachment,

P. O. Box 568337, Orlando, Florida, USA 32856-8337

and LT Paul A. Semper

Navy Nuclear Power School, Orlando, Florida, USA

This paper discusses resonant cavities and their potential sound pressure output when they are modulated hydrodynamically. Rough calculations show that in the frequency range of 10 to 100 Hz source levels in excess of 200 dB re 1 μPa should be achievable. Experimental data from three suboptimum devices showed source levels of 182 dB at 16.6 and 50 Hz and 168 dB at 34.5 Hz. It is expected that with appropriate designs one can achieve greater than 200 dB from 10 to 100 Hz with fairly

small, lightweight devices. Further, with innovative designs one should be able to obtain frequency diversity and perhaps broad bandwidth with a single device.

I. INTRODUCTION

Sound generation is known to be inefficient when the radiating device is small compared to a wavelength of the frequency one wishes to generate. Production of high sound pressure levels at low frequency from devices small compared to a wavelength requires large amounts of acoustic power. For example, to produce 200 dB re 1 μPa at 10 Hz requires 1 kW of acoustic power and a volume displacement of 10^4 cm^3. With efficiencies of the order of 1% for many low-frequency devices, the power amplifier requirement would be about 100 kW. If one could develop a suitable tow-powered source to derive power primarily from a ship's propulsion system, the power might be available without having to provide extra generating equipment on-board the vessel. A vessel such as the U.S. Naval Ship Stalwart (TAGOS-1) has a power plant that delivers 3,200 brake horsepower or about 2 MW of power. This vessel would be capable of towing such a device with about 5% of its power going to sound generation. A highly resonant device might do even better. Here we will consider resonant air cavity devices and give some results from theory and experiment.

II. SOME CONSIDERATIONS FOR PULSATING SPHERES AND RESONANT BUBBLES

From the previous paper in this meeting by Timme, Young, and Blue, let us examine Fig. 1. At 10 Hz a spherical source driven uniformly over its area would require 1 kW of acoustic power in the water to achieve a sound pressure level of 200 dB re 1 μPa. The question now is whether or not that source level is achievable by causing the flow past a 10-Hz resonant bubble to sinusoidally modulate the pressure field in the fluid surrounding the bubble. A candidate source design that we examined previously[1] is shown schematically in Fig. 2. In this case we attached a rubber membrane to a rigid hemisphere to produce the resonant bubble or air cavity. The use of a rigid hemisphere was intended to reduce multi-pole excitation of the resonant cavity. Our objective and approach are shown in Fig. 3. Let us now examine the size and volume displacement necessary to produce a 200-dB source level from a resonant bubble. Figure 4 shows Minnaert's equation[2] for a resonant gas bubble in water. The relationship of the sound pressure produced in the water to the volume displacement of the bubble is given in Fig. 5 for the case of an omnidirectional source. Assume the bubble pulsates linearly with a change of $\pm 5\%$ in its resonant radius; i.e., the rms change in the resonant radius is 3.5%. From this assumption we calculate the rsm volume displacement δV_o as shown in Fig. 6. Combining equations in Figs. 4, 5, and 6 we obtain the acoustic pressure referenced to 1 meter as shown in Fig. 7. Here we see that a 10-Hz resonant bubble at a depth of 9.8 m pulsating at 3.5% rms of the resonant radius (r_o = 0.46 m) will give a sound pressure level of 203 dB re 1 μPa at 1 m. To obtain 200 dB at 100 Hz maintaining the 3.5% rms displacement criteria one would have to place the resonant bubble at a depth of 62.3 m. Its radius at that depth would be 0.088 m.

III. SOME RESULTS FROM SUB-OPTIMUM DEVICES

We have tested three different prototype tow-powered sources at the Naval Research Laboratory. None of the prototypes is close to being optimum, however, the results do show that producing fairly high sound pressure levels from such sources is not that difficult. Figure 8 shows the concept for a 16.6-Hz resonant source. The salient features here are the flow modulator, plastic shroud, and rigid hemisphere. For this device and for a 50-Hz resonant device that we built, the stiffness and loss in the membrane as well as the design of the flow modulators were factors in making the device suboptimum. Figures 9 and 10 show results from these two devices. Source levels of ~ 182 dB were obtained at a tow speed of 1.85 km/hr (1 knot) for both of these devices. Lack of linearity with tow speed causes us some concern. Figure 11 shows the devices were omnidirectional. No measurements of harmonic distortion were made. Figure 12 shows another concept for a tow-powered source that was tested. This device was modeled by LT Semper for his Master's thesis[3] in mechanical engineering at the University of Central Florida. This device corrects a deficiency of the first devices by providing a variable speed motor to control the modulation frequency instead of depending on tuning the flow modulator to rotate at the proper resonant rate. We will not go into detail about the modeling but it involves the elastic moduli of the elastomeric membrane, adds the radiation mass in an ad hoc manner, and calculates the peak modulation pressure as a function of tow speed. Figure 13 shows the calculated source levels as a function of the peak modulation pressure. Since the model used is a linear one, we expect the linear response shown here. For a peak modulation pressure of 0.1 psi theory predicts a sound pressure level of 168 dB at 34.5 Hz. Figure 14 shows the experimental results which agree well at resonance with the theory after selection of appropriate parameters to put into the theory.

IV. DISCUSSION

The results presented here were meant to stimulate thought on tow- or flow-powered devices. We have shown with very crude devices that source levels of 170 to 190 dB are easily obtainable. Our belief is that source levels greater than 200 dB can be obtained from 10 to 100 Hz with rather small, lightweight devices and that with innovative design we can develop devices that have frequency diversity and maybe even fairly broad bandwidth.

REFERENCES

1. H.C. Schau, A.L. Van Buren, and F.J. Rodosta, "Low-frequency, tow-powered sound source," J. Acoust. Soc. Am. 74, 583(A) (1983).
2. M. Minnaert, Phil. Mag. n16 235 (1933).
3. Paul A. Semper, "Mathematical Modeling of a Low-Frequency Cylindrical Sound Transducer," Master's thesis, University of Central Florida, Orlando, FL, 1990.

FIGURE CAPTIONS

Fig. 1 Source level and acoustic power radiated from a harmonically pulsating sphere with $ka << 1$.

Fig. 2 Tow-powered, low-frequency sound source.

Fig. 3 Objective and approach in creating a tow-powered, low-frequency sound source.

Fig. 4 Minnaert's equation for a resonant bubble in water.

Fig. 5 Sound pressure referenced back to 1 m from an omnidirectional source with volume displacement δV.

Fig. 6 Volume displacement for a resonant bubble with 3.5% rms oscillation about r_o.

Fig. 7 Sound pressure level re $1 \mu Pa$ for a 10-Hz resonant bubble at 9.8-m depth pulsating 3.5% r_o rms ($r_o = 0.46m$).

Fig. 8 Flow modulator.

Fig. 9 Sound pressure level vs tow speed.

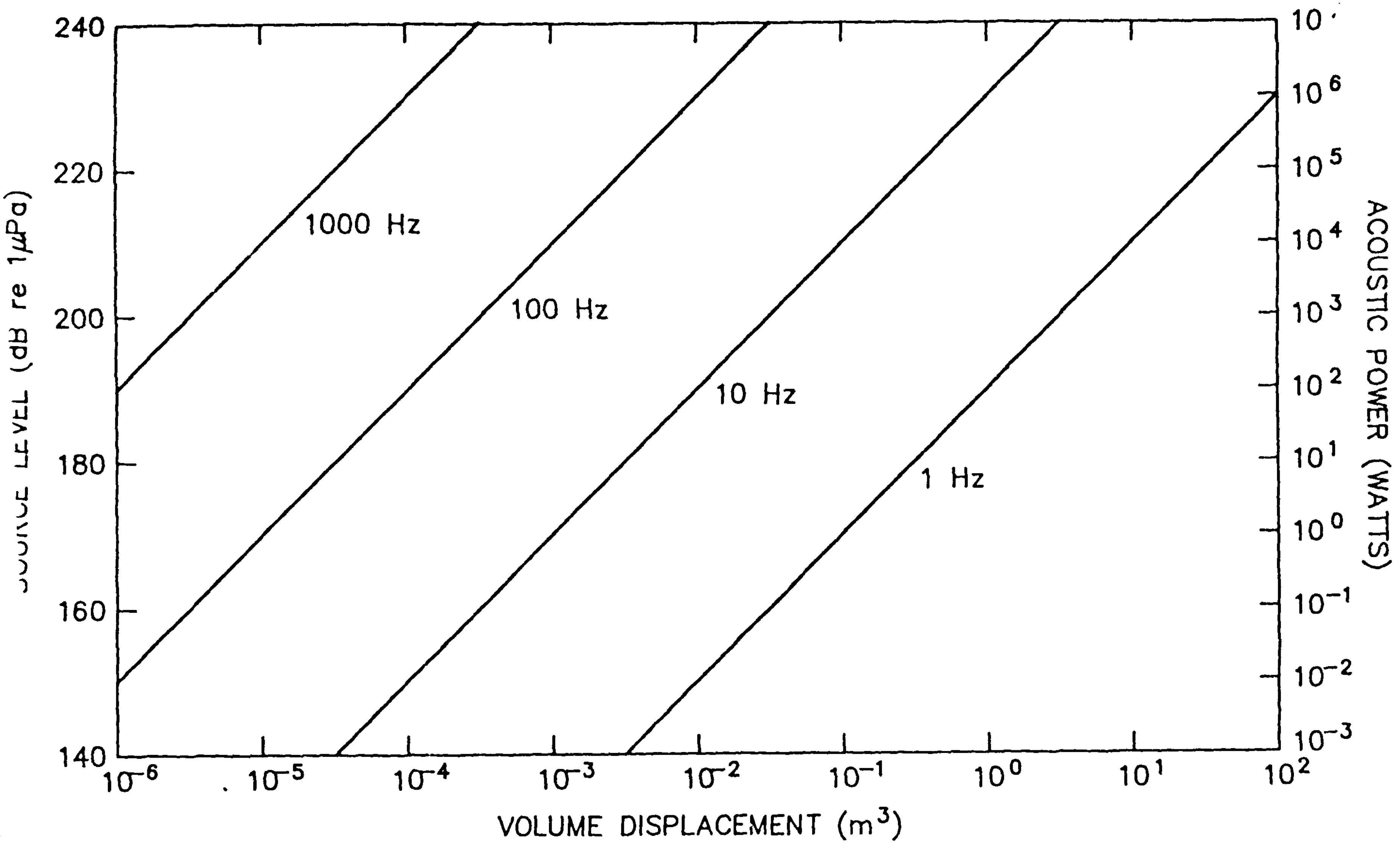
Fig. 10 Sound pressure level vs tow speed

Fig. 11 Directivity of 16.6 and 50 Hz sources.

Fig. 12 Tow-powered sound source.

Fig. 13 Effects of the magnitude of forcing.

Fig. 14 Sound pressure level vs frequency.



SOURCE LEVEL (dB re 1μPa)
240
220
200
180
160
140
ACOUSTIC POWER (WATTS)
10
10 6
10 5
10 4
10 3
10 2
10 1
10 0
10−1
10−2
10−3
1000 Hz
100 Hz
10 Hz
1 Hz
10−6
10−5
10−4
10−3
10−2
10−1
10 0
10 1
10 2
VOLUME DISPLACEMENT (m 3)

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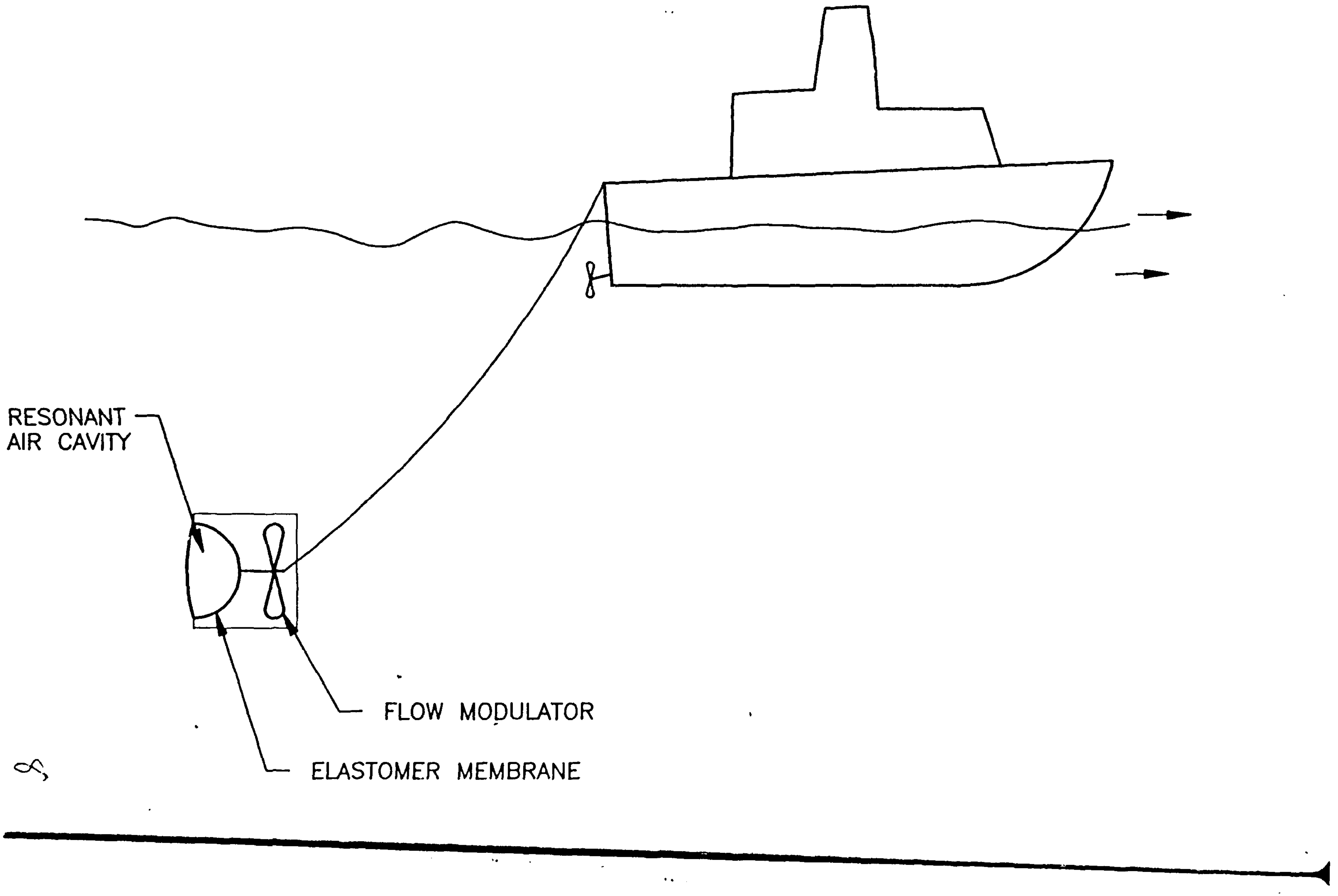

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OBJECTIVE

Produce a robust, inexpensive sound source capable of high (>200 dB) sound pressure levels at low (<100 Hz) frequency and whose primary source of power is derived from being towed through the water.

APPROACH

Investigate theoretically and experimentally a new sound source concept involving a resonant air cavity excited by a modulated flow field.

$$f_o \, r_o = \sqrt{\frac{3\gamma \, P_h}{4\pi^2 \rho}}$$

f_o = resonant frequency

r_o = radius at resonance

γ = adiabatic constant

P_h = hydrostatic pressure

ρ = density

$$f_o \, r_o = 3.26 \sqrt{\frac{h + 9.8}{9.8}}$$

h = water depth in meters

r_o in meters

$$|p|_{1m} = \frac{\omega^2 \rho}{4\pi} \delta V$$

ω = angular frequency

ρ = density

δV = volume displacement

Volume of resonant bubble

$$V_o = \frac{4}{3} \pi r_o^3$$

$$(\delta V)_{3.5\%} = \frac{4}{3} \pi \left[(1.035)^3 - 1\right] r_o^3$$

$$= 0.457 \; r_o^3$$

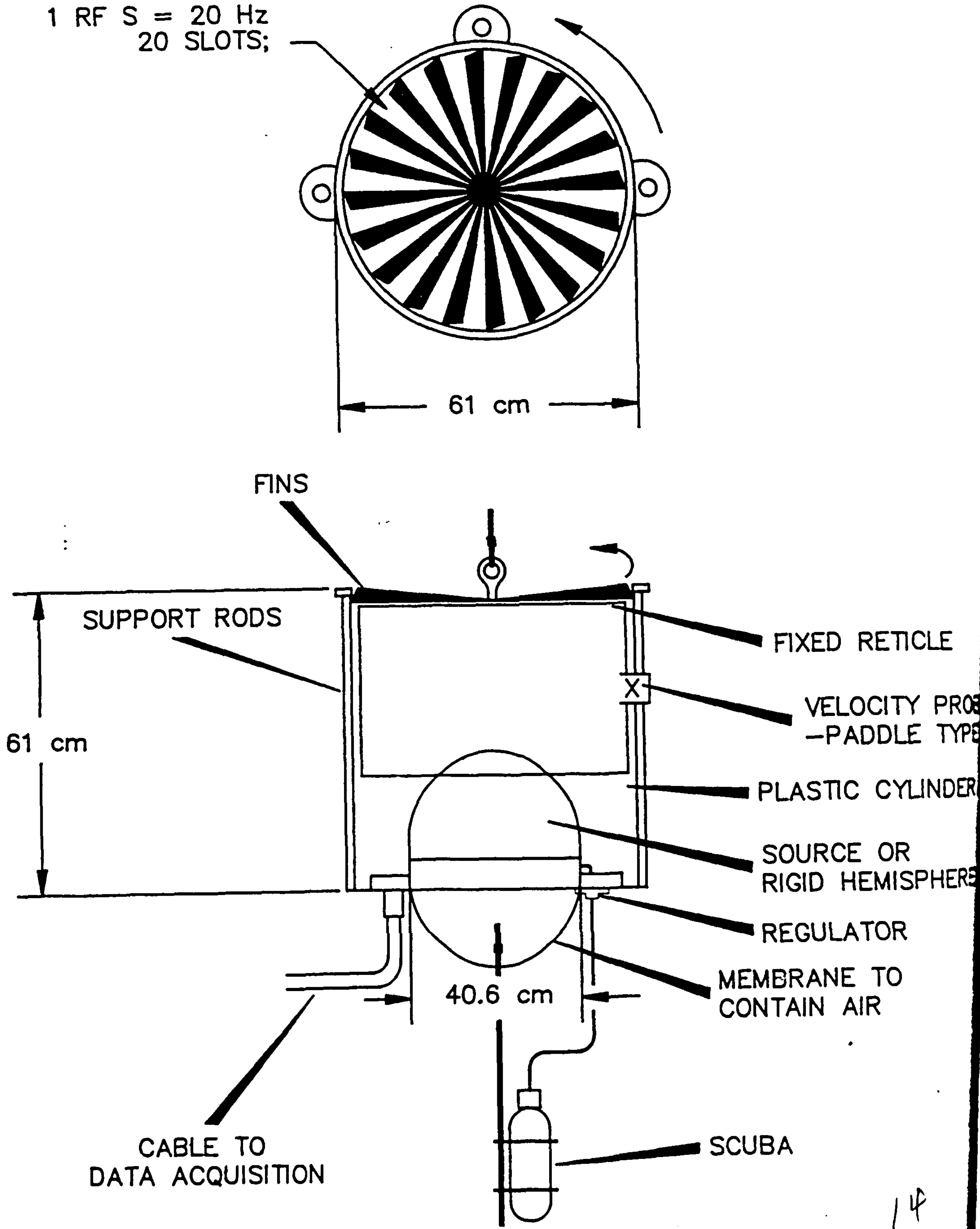
$$|p|_{1m} = \frac{4.95 \times 10^4}{f_o} \left(\frac{h + 9.8}{9.8}\right)^{3/2}$$

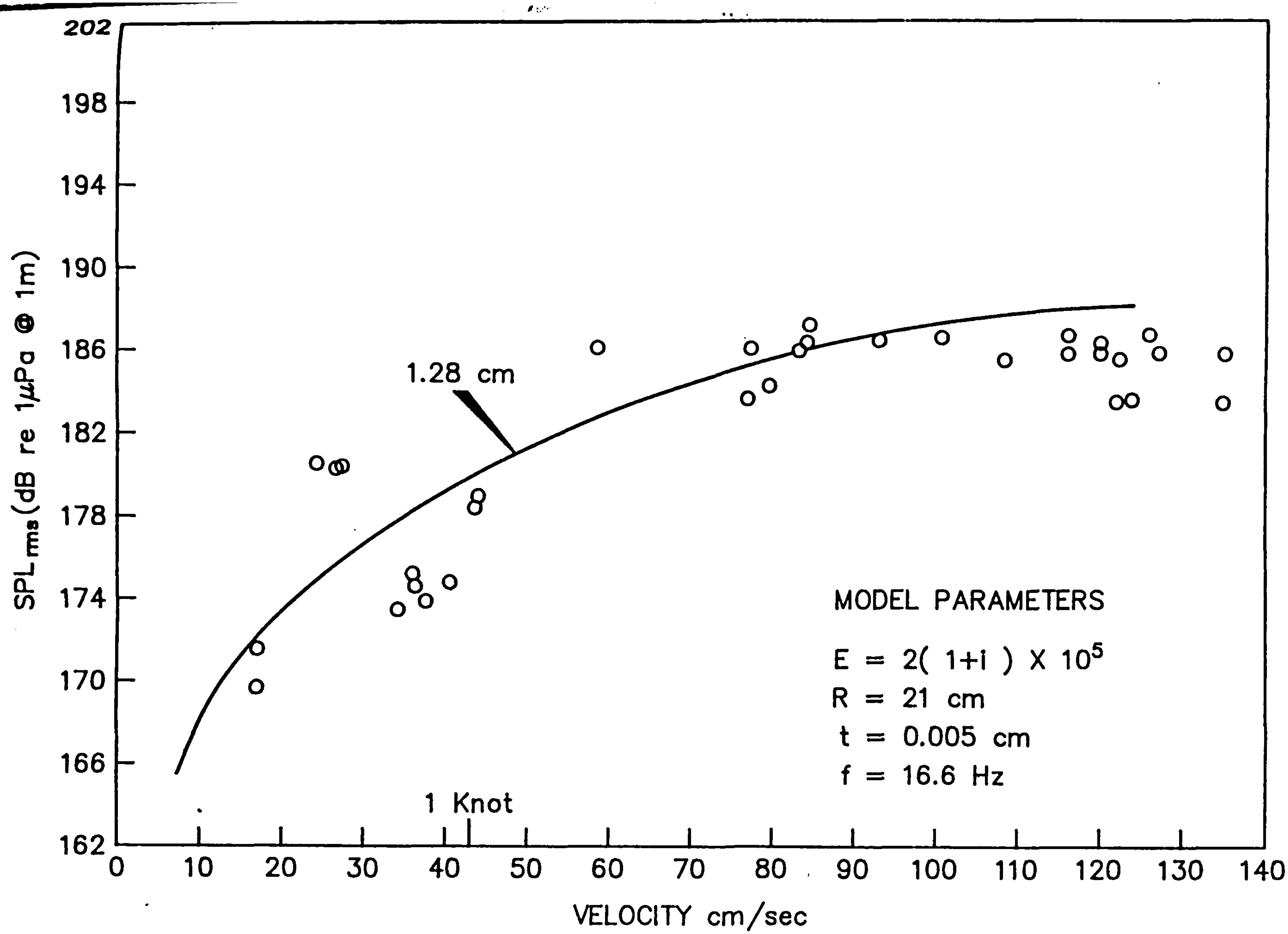
$$SPL = 213.9 - 20 \log f_o + 30 \log \left(\frac{h + 9.8}{9.8}\right) \text{ dB re } 1\ \mu\text{Pa}$$

For $f_o = 10$ Hz and $h = 9.8$ m

$$SPL = 203 \text{ dB}$$

FLOW MODULATOR





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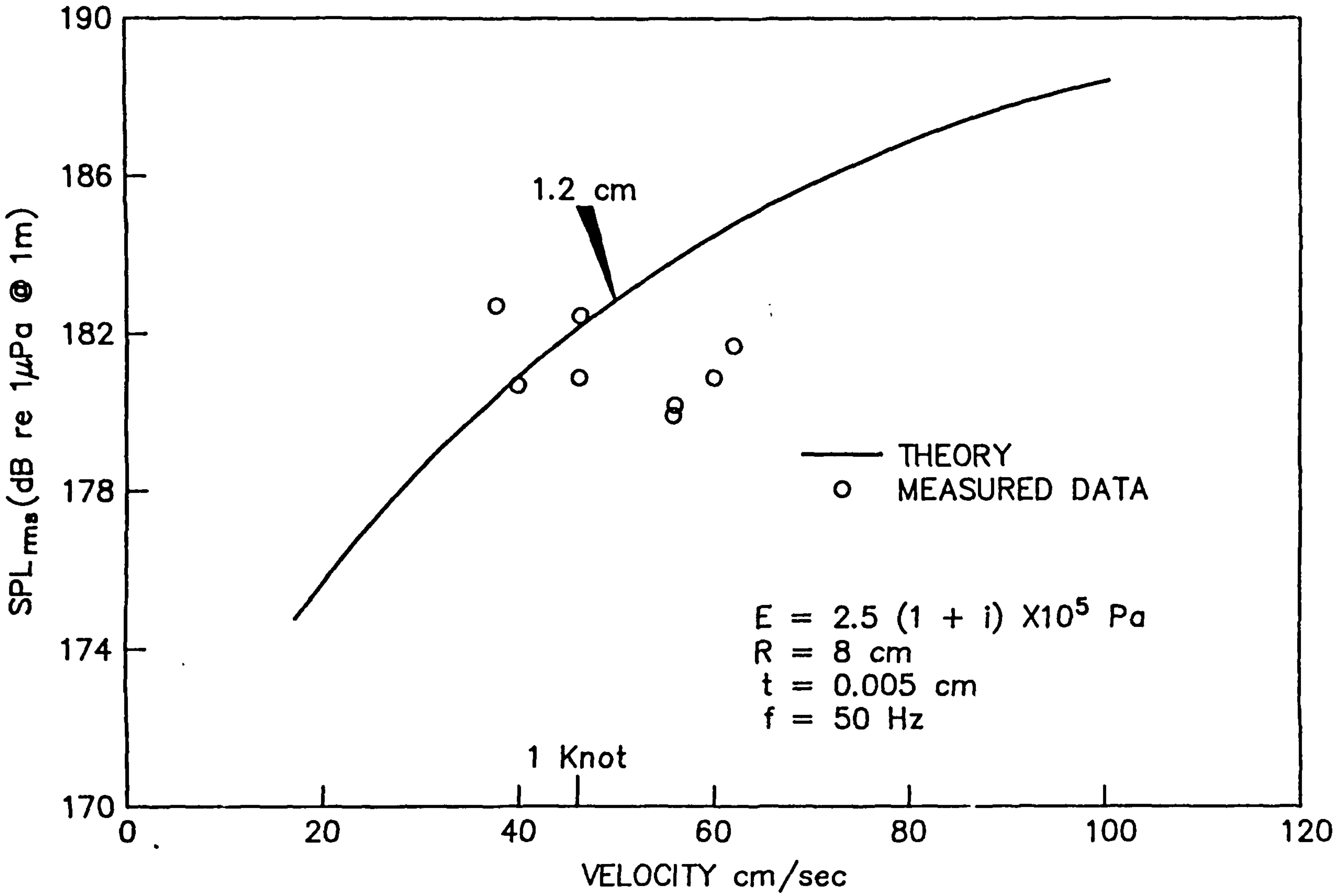
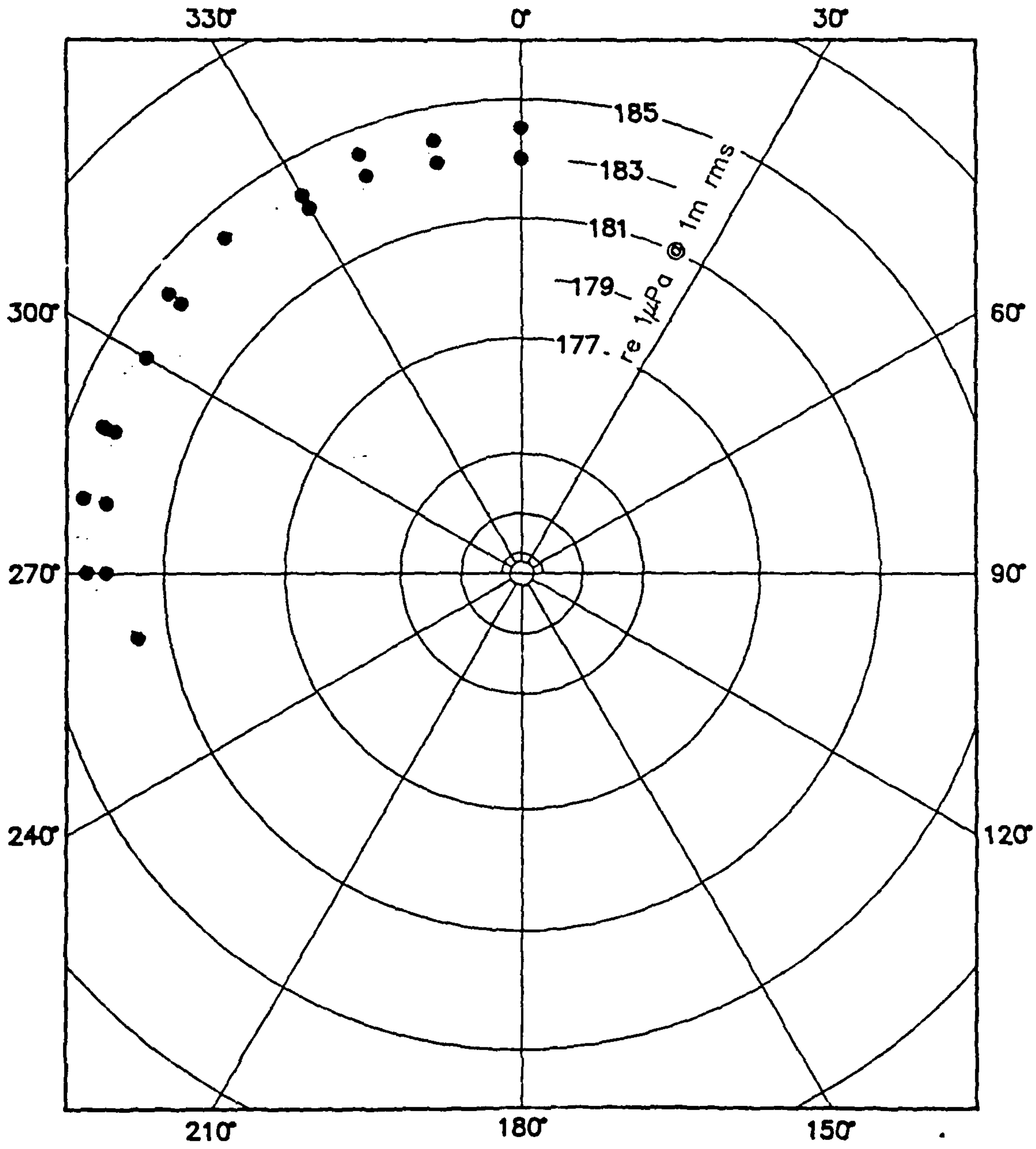
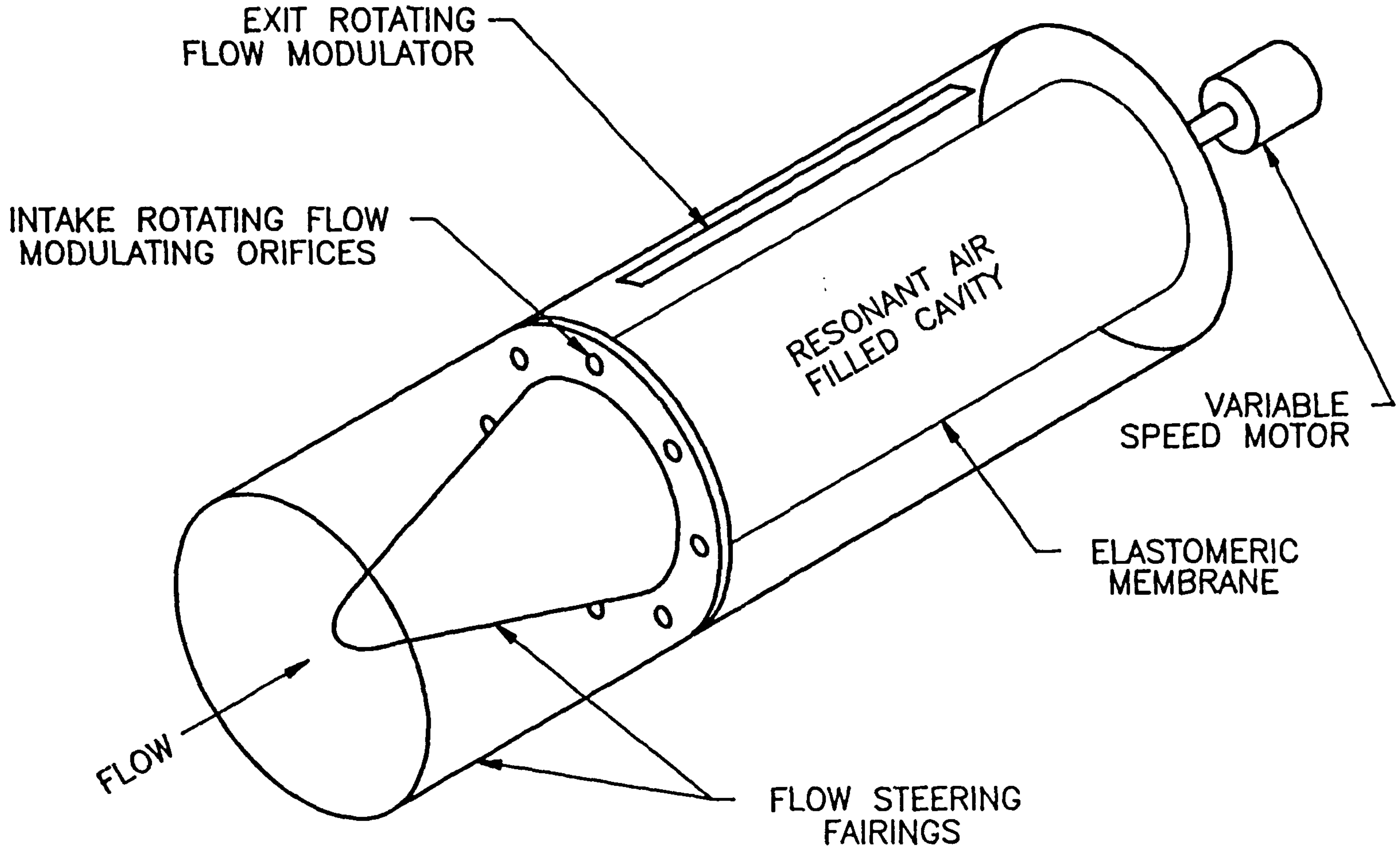


SPL$_{rms}$(dB re 1μPa @ 1m)
190
186
182
178
174
170
0
20
40
60
80
100
120
VELOCITY cm/sec
1 Knot
1.2 cm
THEORY
MEASURED DATA
E = 2.5 (1 + i) X10^5 Pa
R = 8 cm
t = 0.005 cm
f = 50 Hz


330°
0°
30°
300°
60°
270°
90°
240°
120°
210°
180°
150°
185
183
181
179
177
re 1μPa @ 1m rms


EXIT ROTATING
FLOW MODULATOR
INTAKE ROTATING FLOW
MODULATING ORIFICES
RESONANT AIR
FILLED CAVITY
VARIABLE
SPEED MOTOR
ELASTOMERIC
MEMBRANE
FLOW
FLOW STEERING
FAIRINGS

200

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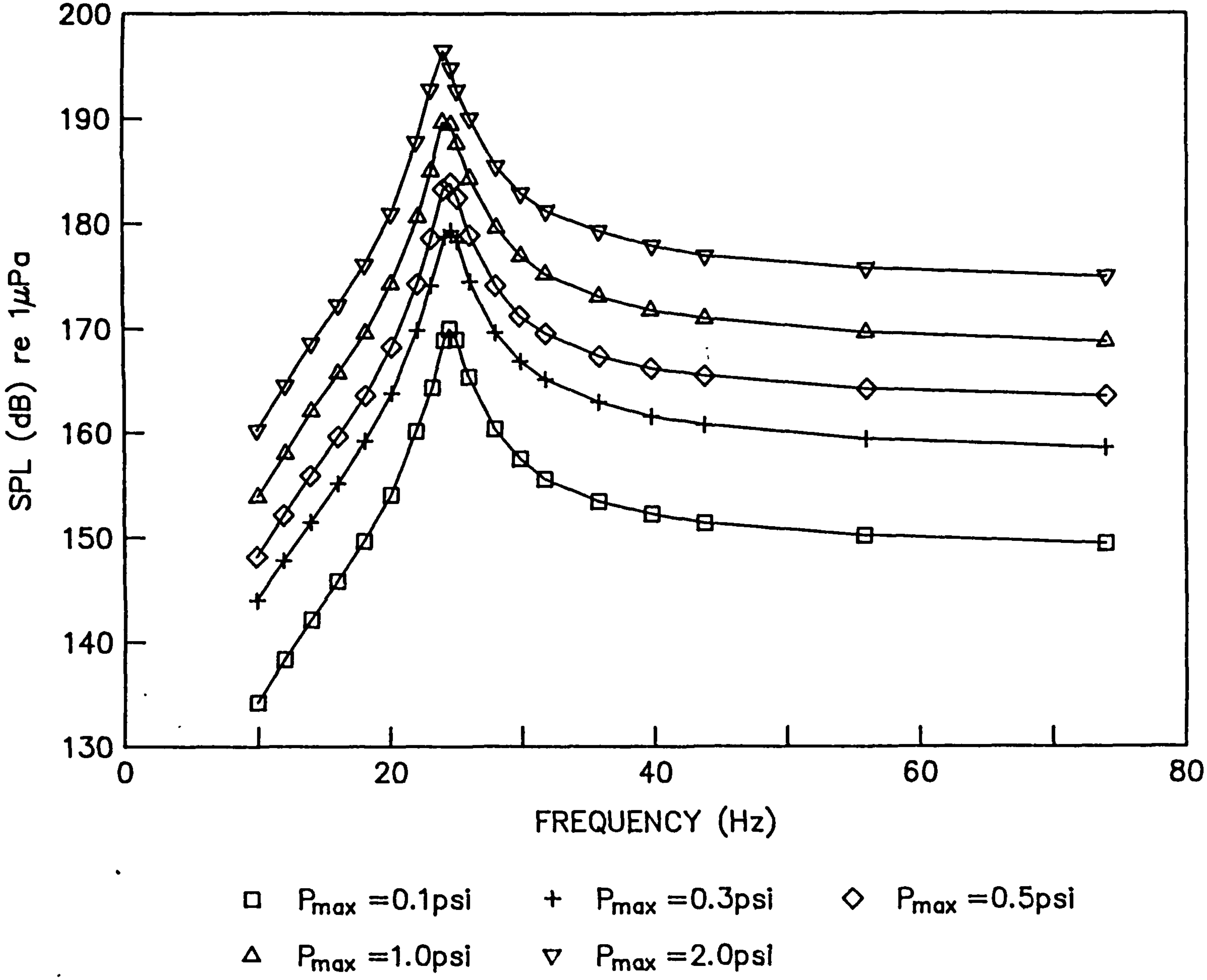

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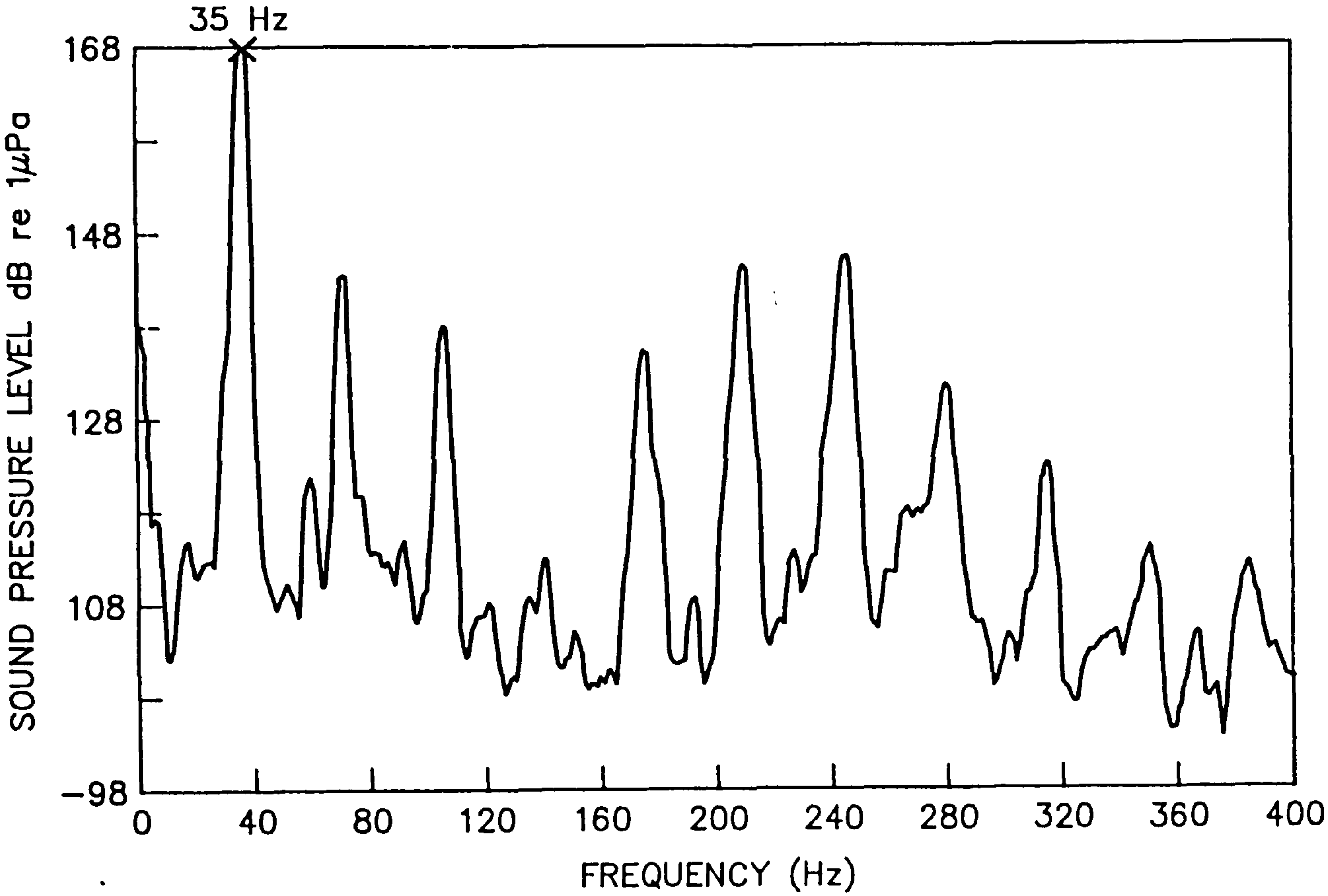
35 Hz
168
148
128
108
−98
0
40
80
120
160
200
240
280
320
360
400
FREQUENCY (Hz)
SOUND PRESSURE LEVEL dB re 1μPa

2C